Skin Hazard Evaluation of the

ACP-2A

Near-Infrared Pointer

Tri-Service Directed Energy Bioeffects Complex

Radiofrequency Radiation Division
Occupational and Environmental Health Directorate
U.S. Air Force Armstrong Laboratory

Navy Medical Research Institute
Detachment Brooks Air Force Base

U.S. Army Medical Research Institute
Walter Reed Army Institute of Research
Detachment Brooks Air Force Base

AL/OER-TR-1997-0134
NMRI DET Brooks AFB 97-37
USAMRI/WRAIR TR

19980409031

Skin Hazard Evaluation of the

ACP-2A

Near-Infrared Pointer

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	March 1998	FINAL REPORT, 01 AUG 1997-30 SEP 1997

4. TITLE AND SUBTITLE

Skin Hazard Evaluation for ACP-2A Near-Infrared Pointer

5. FUNDING NUMBERS

6. AUTHOR(S)

Dennis W. Blick, Jerri A. Tribble, Thomas J. Walters, Peter R. Edsall,
James H. Merritt, Charles W. Beason, and Peter Demitry

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

U.S. Air Force Armstong Laboratory, Radiofrequency Radiation Division
U.S. Naval Medical Research Institute Detachment, Brooks Air Force Base
Walter Reed Army Institute of Research, US Army Medical Research Institute Brooks
AFB Detachment, Brooks Air Force Base, Texas 78235

8. PERFORMING ORGANIZATION

AL/OE-TR-1997-0134

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSORING/MONITORING

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

In response to safety concerns expressed by a USAF operational unit, a tri-service research team at the USAF Armstrong Laboratory tested a fielded near-IR pointing device for potential skin hazards to the users. The power output and beam profile were measured in the U.S. Army Medical Research Detachment at Brooks AFB. The sensory effects of the device were then tested at the Naval Medical Research Institute, Detachment Brooks AFB. Skin temperature was measured with a calibrated infrared camera, sampling at a 5 Hz rate before, during and after exposure. Despite the potential for delivery of large power densities (> 140 W/cm^2) to very small skin areas, no sensory or skin damage effects could be detected in human subjects under worst-case exposure conditions. The maximum change in skin temperature observed was approximately 2°C. The Tri-Service Team concludes that the tested device presents no hazards to operational personnel due to possible inadvertent exposure of their skin. The device can produce no sensory effects that might prove a distraction for aircrew. Its output power is far below that necessary to produce skin damage under any conditions. Fielded eye protection devices are more than adequate to prevent eye damage.

14. SUBJECT TERMS	15. NUMBER OF PAGES
skin sensation, infrared laser, skin damage	42
	16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
U	U	U	UL

NOTICES

This interim report was submitted jointly by personnel of the Radiofrequency Radiation Division, Occupational and Environmental Health Directorate, USAF Armstrong Laboratory (Human Systems Division, AFMC), the U. S. Naval Medical Research Institute, Detachment Brooks AFB, and the US Army Medical Research Institute, Walter Reed Army Institute of Research.

This research was supported in part by the USAF Armstrong Laboratory under Contract F33615-90-C-0604, by the Naval Research and Development Command under work unit N64771N BS21 M000933 0031513, and by the US Army Medical Research Institute.

When U.S. Government drawings, specifications, or other data are used for any purpose other than in connection with a definitely Government-related procurement, the United States Government incurs no responsibility or any obligation whatsoever. The fact that the government may have formulated or in any way supplied the said drawings, specifications, or other data, is not to be regarded by implication, or otherwise in any manner construed, as licensing the holder or any other person or corporation; or as conveying any rights or permission to manufacture, use, or sell any patented invention that may in any way be related thereto.

The views expressed in this article are those of the authors and do not reflect the official policy or position of the Department of the Air Force, Department of the Navy, Department of the Army, Department of Defense, or the U.S. Government.

Human subjects tested in this work were used in accordance with an approved human use protocol and in accordance with Air Force Instruction 40-402, "Using Human Subjects in Research, Development, Test, and Evaluation," and 32 CFR 219, "Policy for the Protection of Human Subjects."

Trade names of materials and/or products of commercial or nongovernmental organizations are cited as needed for precision. These citations do not constitute official endorsement or approval of the use of such commercial materials and/or products.

This report has been reviewed and is approved for publication.

James H. Merritt

James H. Merritt, Project Scientist

David N. Erwin

David N. Erwin, Ph.D., Director
Occupational and Environmental Health
U.S. Air Force Armstrong Laboratory

Randal K. LeBlanc

LT Randal K. LeBlanc, MSC, USN
Officer in Charge, Naval Medical Research Institute, Detachment Brooks AFB

Bruce E. Stuck

Bruce E. Stuck, Director
Walter Reed Army Institute of Research
U.S. Army Medical Research Detachment
Brooks AFB, TX

Skin Hazard Evaluation of the ACP-2A Near-Infrared Pointer

by

Dennis W. Blick[†], Jerri A. Tribble[‡], Thomas J. Walters[†],

Peter R. Edsall[#], James H. Merritt*, Charles W. Beason, and Peter Demitry**

[†]Systems Research Laboratories, Inc.; [‡]Naval Medical Research Institute, Detachment Brooks AFB; [#] Walter Reed Army Institute of Research, US Army Medical Research Institute Detachment Brooks AFB; *Radiofrequency Radiation Division, Directorate of Occupational and Environmental Health, U. S. Air Force Armstrong Laboratory, Human Systems Center, Brooks AFB, Texas

ABSTRACT

In response to safety concerns expressed by a USAF operational unit, a Tri-Service research team at the USAF Armstrong Laboratory tested a fielded near-IR pointing device for potential skin hazards to the users. The power output and beam profile were measured in the U.S. Army Medical Research Detachment at Brooks AFB. The sensory effects of the device in volunteer human subjects were then tested at the Naval Medical Research Institute Detachment at Brooks AFB. Skin temperatures were measured with a calibrated infrared camera, sampling at a 5 Hz rate before, during and after exposure. Despite the potential for delivery of large power densities ($\geq$ 140 W/cm^2) to very small skin areas, the human subjects were unable to detect exposure under the worst-case exposure conditions. The maximum increase in skin temperature observed was approximately 2°C. The Tri-Service Team concludes that the tested device presents no hazards to operational personnel from possible inadvertent exposure of their skin. The device can produce no sensory effects that might prove a distraction for aircrew. The output power is far below that necessary to produce skin damage under any conditions. Fielded eye protection devices are more than adequate to prevent eye damage.

On 14 May 1997 the Optical Radiation Division (AL/OEO) responded to a request for safety evaluation of a near-infrared (near-IR) laser pointing device (ACP-2a, Night Vision Equipment Co., Inc.) for safe operation in the cockpit of an A-10 aircraft. The response concluded that existing Laser Eye Protection (LEP) provided adequate protection from ocular hazards, but that "there is a skin hazard associated with exposure to this laser ." According to the current laser safety standard, the skin safe distance for this device is 18 m. Since there are several sources of specular reflection in cockpits where the device is used, Air Combat Command (ACC) users feared that any unintentionally exposed skin (e.g., at the neck or wrist) might be damaged if the device were accidentally activated (or if inactivation failed) when it was not directed through the canopy, as it would be in normal use. Reflections off the canopy (~10% of incident energy) would not pose a skin hazard under any circumstances. Based on the AL/OEO evaluation, ACC requested clarification of the nature and extent of the skin hazard. Responding to a request from users of the device, a Tri-Service working group including personnel from the Radiofrequency Radiation Division (AL/OER), the Naval Medical Research Institute Detachment Brooks AFB (NMRI DET), and the US Army Medical Research Detachment, Walter Reed Army Institute of Research (USAMRD-WRAIR) was formed. This group developed a plan for testing the sensory effects of the device on human skin under existing AL/OER human use protocols.

The most probable bare-skin exposure is on the forearm near the wrist, where gaps between flight suit and gloves might occur, or near the jaw-line. Our previous research examined near-IR sensory effects on the human back, so testing at this site was desirable for comparisons with prior work. Differences in IR sensitivity at warmth detection threshold between the back and forearm and facial areas have been documented (Stevens et al., 1974). The dependency of sensory effects (e.g., warmth detection threshold) on the area stimulated have also been demonstrated (e.g., Stevens et al., 1974). The threshold varies almost inversely with the area stimulated below an area of about 60 cm^2. For areas larger than about 60 cm^2, the threshold is a constant low value. For very small areas, the threshold can be orders of magnitude larger. Safety standards are based on exposure of much larger areas (3.5 mm aperture, i.e., beam diameter), and include an order of magnitude safety factor. Thus, a device like the ACP-2a, which deposits energy in a very small area, might produce minimal or no sensory effects, and no damage, even though the peak power delivery (at a point) might exceed established laser safety standards.

METHODS

The only control on the laser (see Fig. 1) was a focus (i.e., beam divergence) control. For purposes of these tests, this control was set in a "worst case" beam divergence, producing a spot that was as small in area as possible on the subjects' skin. Control of power delivered to the skin was achieved by varying duration of exposure. During testing of the laser, the subjects, stripped to the waist, sat quietly while the laser illuminated the skin on their backs. During each trial, skin heating was measured over the exposed area by IR thermography, so that functional relationships between skin temperature and intensity, duration, and sensory effects could be developed. Infrared thermography was performed using a Radiance 1 Infrared Camera System (Amber Engineering, Inc.). The camera contains a focal plane array composed of 256 x 256 indium antimonide sensors. Using black body calibration, the system is accurate to within ± 0.1 °C. With a 25 mm lens and the camera located ~25 cm from the subject, the spatial resolution was 231 X 231 microns/sensor. Images were sampled at a rate of 5 images/second, beginning 1 s before and continuing for 3 s after exposure, and stored for later analysis. The camera has a long-wave-pass characteristic, with a cut-off wavelength of 3 microns. Thus it is totally insensitive to near-IR from the ACP-2a reflected by the skin. Image analysis was performed on the stored images (*.fts format) using Image Desk™ image analysis software. The images were calibrated for temperature using a calibrated black-body radiator. The surface temperature in the 85.4 mm² area surrounding the irradiated area was analyzed. From this area the following parameters were determined for each trial: 1) mean baseline temperature (sampled across the 85.4 mm² area); and 2) peak temperature (highest temperature pixel) at the end of each trial.

Sensory effects were assessed by asking six male Caucasian subjects, age 32-56, to indicate whether or not each exposure could be detected and, if so, to indicate the nature of the sensation (e.g., warmth, pain). The subjects were practiced observers, having participated previously in warmth detection threshold studies employing IR stimulation. Each subject was exposed 3 times at each of 2 durations: 3- and 10-seconds. Exposures were separated by at least 1 minute. Subjects were asked to minimize movement by holding their breath during exposures. Back position was controlled by resting the back against the edge of the optical bench holding the IR pointer, shutter, and IR camera.

ACP-2a Dosimetry. The wavelength was determined to be 827.3 nm using a single monochromator (Oriel Instaspec III™) with 1 nm bandwidth. The beam profile at 20 cm was measured with the beam divergence adjusted to the minimum spot size. It was found to be elliptical with a minor axis of 0.1 mm and a major axis of 0.2 mm. The major and minor axes were determined by the software, based on where the measured intensity fell to a percentage of the peak intensity set by the user. We set that percentage of peak to 36.8% (1/e). This measurement was made twice using a Big Sky Software Corp.™ beam profiling system (Model No. BVA-101) with ~25 micron CCD element size (so that the major axis activated ~ 20 elements). This spot size is about an order of magnitude smaller than that reported by AL/OEO, who performed similar tests on another device of the same type. Since OEO was interested in conservative determinations of the eye-safety stand-off ranges (NOHD), they performed their measurements with the ACP-2a adjusted to minimum divergence rather than minimum spot size.

The laser was mounted behind a Uniblitz™ variable shutter (model LS3ZM2 with T132 controller). Through the shutter (in the open position) the power was measured using a Scientech Model MD10 power meter with MC2501 calorimetric head (25.4 mm aperture). Power prior to subject exposure was 90 mW. After the 5th subject, multiple readings of the peak power observed during a 3 s shutter opening were collected and averaged. The average power (± one standard deviation) after five subjects (< 2 h continuous operation) was 32.6 (±1.3) mW. The decline appeared to be due to changes in battery voltage, which fell from 3.2 to 2.8 V. With a fresh set of batteries, power returned to 92.4 (± 1.6) mW. We retested subject TD and recorded power before (91.5 (± 2.2) mW) and after the exposure (83.9 (± 1.6) mW). Three other subjects who had been tested before subject TD were also retested with new batteries in place. Laser output was >80 mW at the end of each of these tests.

Based on the beam characteristics described above, the maximum power density to which a very small (~.06 mm^2) area of skin could be exposed would be 140 W/cm^2. The actual maximum power density to which the subject was exposed was probably much smaller, since the magnitude of power density is greatly affected by the spot size, which was determined in a separate laboratory. The spot size at a distance of 20 cm (i.e., the subject plane) was found to be very sensitive to the beam divergence adjustment on the ACP. Since the beam divergence adjustment for minimum spot size at 20 cm was not at the end of the adjustment range, the position was marked on the device and an effort was made to reproduce this position in the exposure laboratory. However, the best way to determine the actual spot size would have been to position the profiling system at the actual subject location. Since the profiler was not available in the exposure laboratory, and the operational need for this study was so immediate, we placed a higher priority on determining the safety of this device as it might be used in the field. If the spot size that AL/OEO measured is used, the calculated power density would be ~1.4 W/cm^2. Reductions in power output due to reductions in battery voltage would reduce the maximum power density even further. While the power densities calculated above exceed the MPE specified by ANSI Z136.1, it should be noted that the standard is based on an aperture size (beam diameter) of 3.5 mm. If the power concentrated in the very small output beam of the ACP-2a were dissipated over such a large area, the average power density would be well below the MPE.

RESULTS

DETECTION THRESHOLDS: The most important result was that *none* of the six subjects exposed to the laser beam at it's most compact point could detect whether the laser was on or off. This was true for two durations of exposure: 3 s and 10 s. Testing was performed under worst-case conditions that would never be duplicated in the field: the laser was fixed firmly in place and the subjects were seated, holding their breath, and attempting to minimize movement. Although the skin of the back was tested, we are confident that the slightly more sensitive skin of the face or neck would also be unable to detect the output of the laser under field conditions, because the small difference in sensitivity (Stevens et al., 1974) would be overcome by conditions in the field that would greatly reduce the likelihood of detection (e.g., distraction, movement of the beam over the skin, etc.).

IR THERMOGRAPHY: Figure 2 shows the mean (± s.e.m) temperature increase for 3-s (upper panel) and 10-s (lower panel) exposures for 6 subjects. Because the exposed area was so small, considerable variation in the heating effects probably arose from very small movements of the subject causing the energy to be deposited over wider areas of skin. Individual results from the subject who showed the least variability (and thus probably made the fewest/smallest movements relative to the laser beam) are shown in

Figure 3. In all cases, skin temperature rose to a maximum in the first 5 to 6 s, with little or no further increase to the end of the 10-s exposure period. Figure 4 is a picture of the subject's back showing both the laser spot and the resulting spread of tissue heating. The digital camera used to make this picture apparently has spectral sensitivity extending through the near IR and into the far IR at which the skin radiates heat. Figure 5 shows the spatial distribution of temperature at the end of the 3rd 10-sec exposure shown in Fig. 3. The IR camera used to generate this figure has a wavelength cutoff at (and beyond) 3 microns, so the reflected energy from the laser beam does not affect its readings. This figure illustrates the maximal lateral spread of heat in this subject's skin. It shows that the energy from the very small spot spreads over a much larger (approx. 5 mm diameter) area laterally. Thermal modeling studies (Riu, et al., 1997) indicate that substantial vertical spreading into the deeper layers of the skin also occurs during this duration of exposure.

Discussion

The results reported here support and extend AL/OEO's conclusion that the skin hazard indicated by the relationship between laser pointer output power density and the published safety standard is indeed minimal or nonexistent. While the device is capable of producing power density levels that are apparently hazardous, the extremely small areas in which energy is deposited renders the skin hazard insignificant. This is probably due to several mitigating factors:

1) Diffusion of heat from such a small region is sufficiently fast to prevent temperature rises from reaching warmth detection threshold. Figure 5 shows

that such diffusion did, in fact occur, as temperatures above the surrounding baseline were observed over an area more than 5 mm in diameter.

2) Detection threshold increases dramatically as the area stimulated is reduced (Stevens et al., 1974).

3) Small movements of the subject relative to the beam position "smear" the energy deposition over a larger effective area, reducing the energy deposition at any given location.

Since this "smear" is likely to be much greater under any conceivable conditions in the field, our finding that temperature increases in the skin are far from those required to produce damage (or even perception of the beam) indicates that no hazard exists from the standpoint of inadvertent skin exposure. This conclusion is further reinforced by the fact that the pointer would typically be adjusted for minimum beam divergence in actual use, not adjusted to minimize spot size at the skin exposure location, as was the case in our tests.

AL/OEO has reassessed the skin hazard (AL/OE-CL-1997-0131), and concluded that no special precautions are necessary, in agreement with our findings.

References

Riu, P. J., Foster, K. R., Blick, D. W., and Adair, E. R. A thermal model for human thresholds of microwave-evoked warmth sensations. *Bioelectromagnetics*, 1997 (in press).

Stevens, J. C., Marks, L. E., and Simonson, D. C. Regional sensitivity and spatial summation in the warmth sense. *Physiol. Behav.* **13**(6) 825-835, 1974.

Figure Legends

Figure 1. ACP-2a Pointer, shown mounted on pilot's glove. The device is actuated by a switch that can be pressed with the thumb. It is powered by AA batteries (2) in the pocket on the back of the hand. The red safety cap would be dismounted during operation.

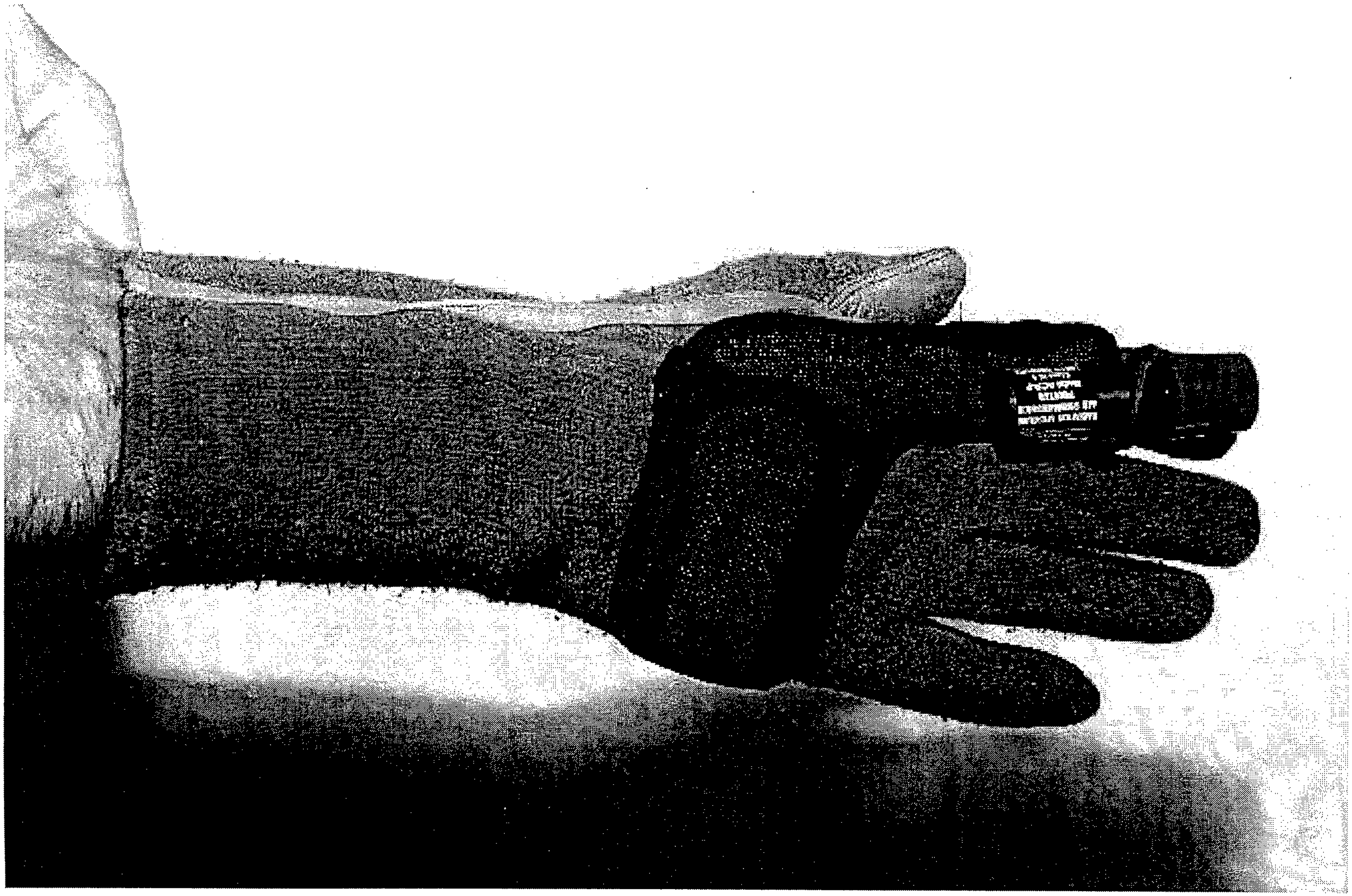
Figure 2. Panel A shows the mean (± S.E.M) temperature change at the peak of the temperature profile in 6 subjects exposed for 3 s. Panel B shows the same results for a 10-s exposure.

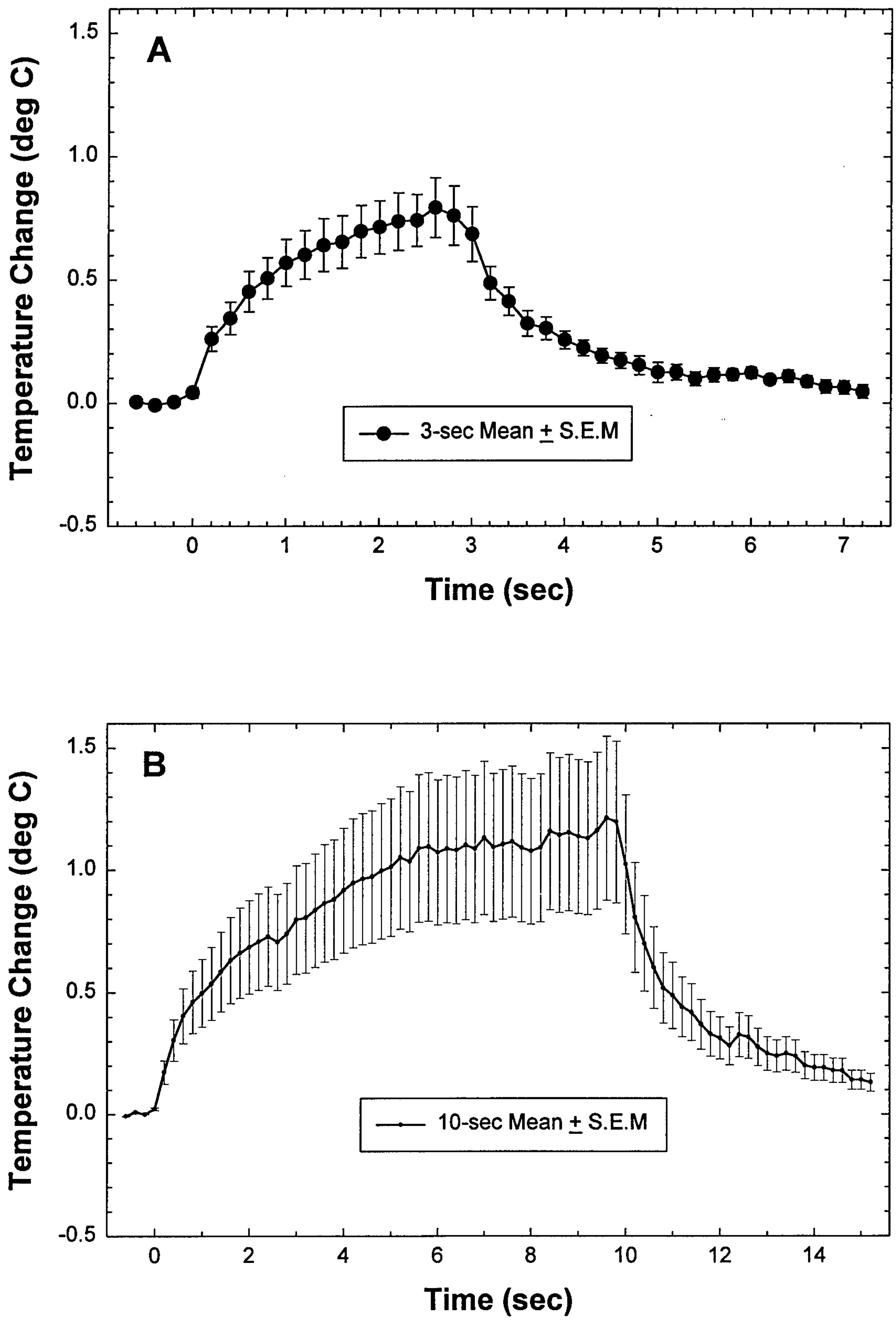
Figure 3. Change in peak temperature over time, during single exposures, in the individual subject with the least variability Thin lines show individual exposures; thick lines indicate the means of 3 exposures.

Figure 4. Digital photograph of Subject TD's back during a 10-s exposure. The digital camera's spectral response extends into the far IR, so the area of warmed skin is clearly visible. The enlargement indicates that the area of skin radiating heat corresponds to the area of skin with elevated temperature shown in Figure 5.

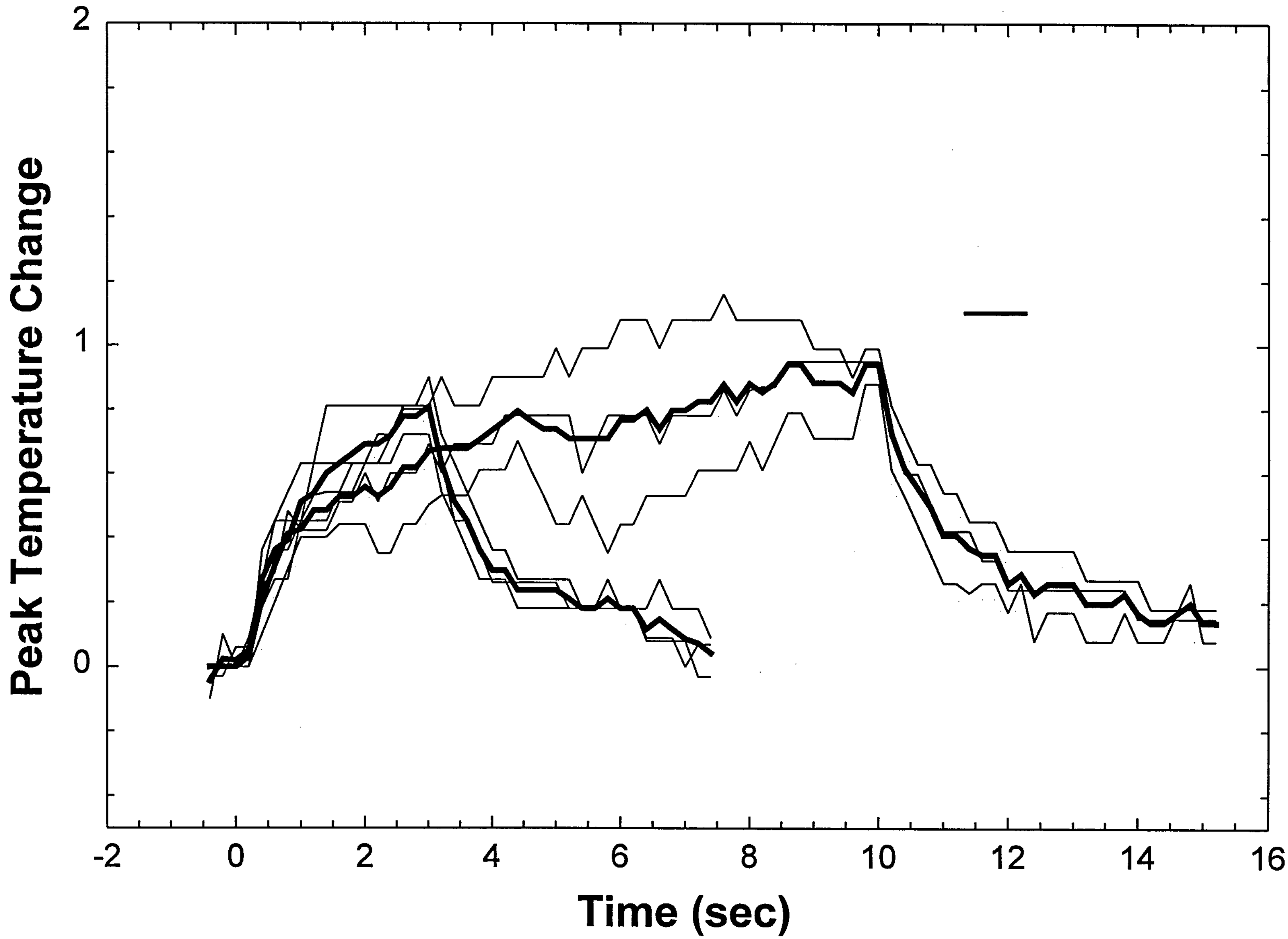
Figure 5. Three-dimensional plot of the temperature profile at the end of the 3rd 10-s exposure illustrated in Fig. 3. Temperature is plotted as a function of distance (in mm) across the back skin in 2 dimensions.

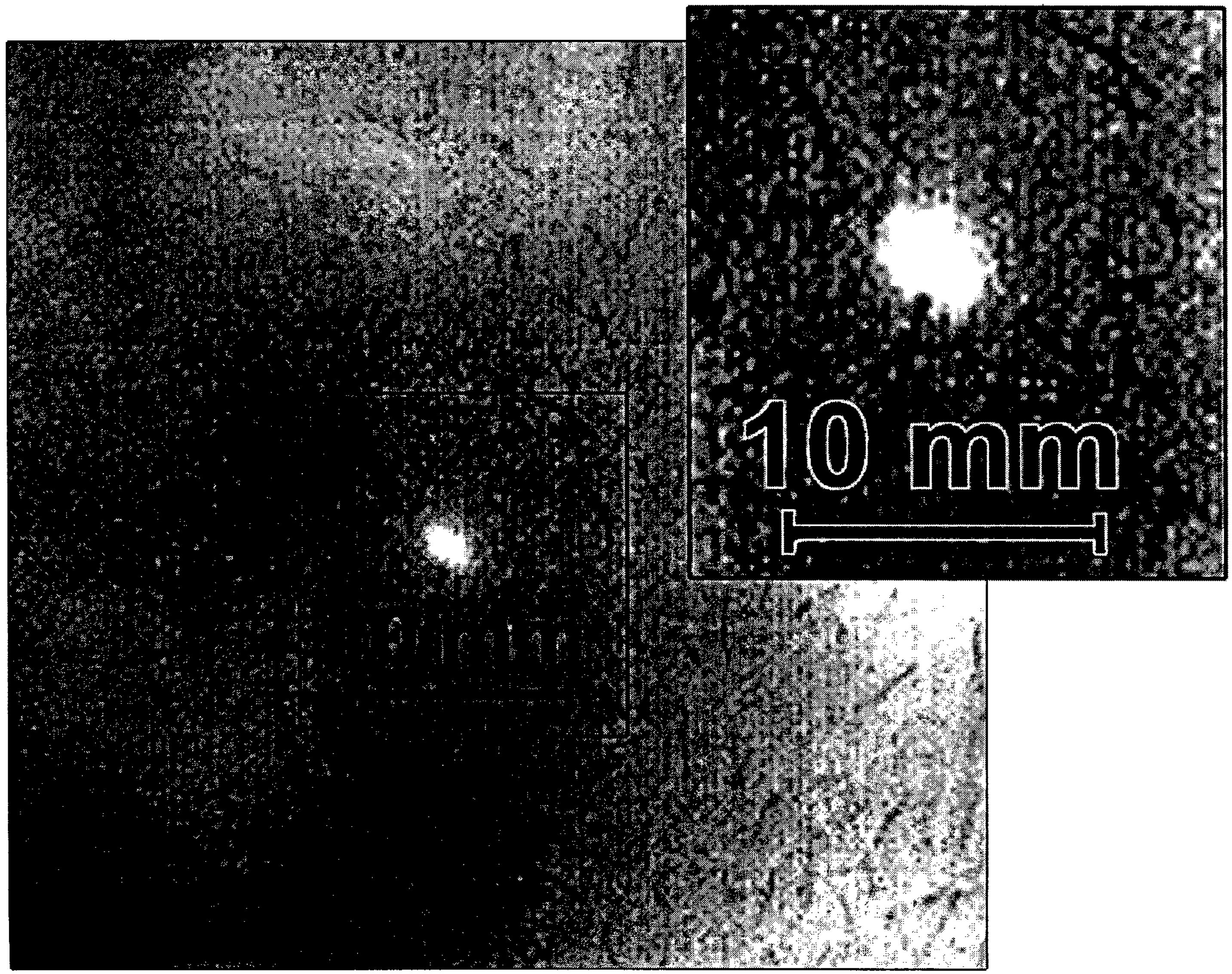
ACP-2a

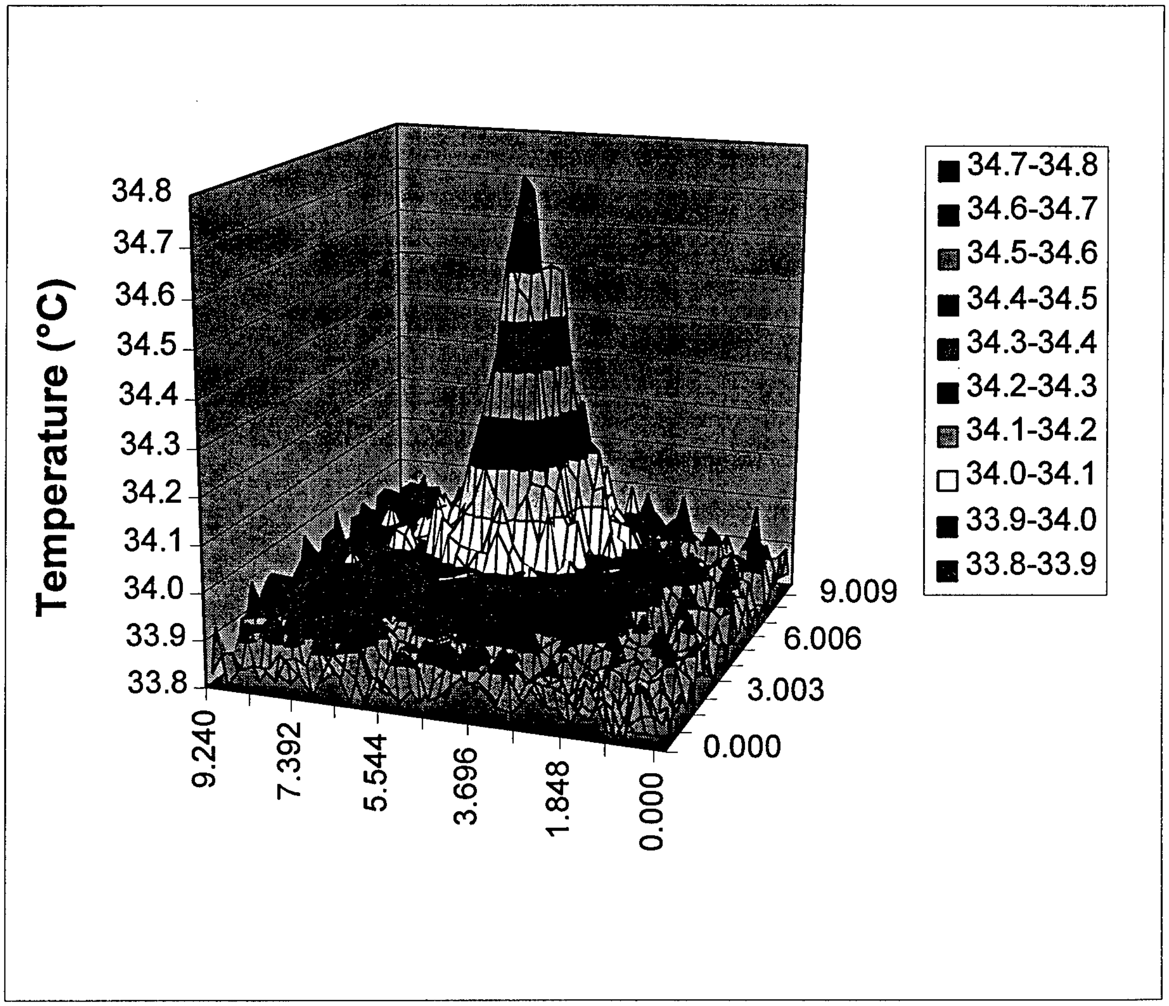



A
3-sec Mean ± S.E.M
Temperature Change (deg C)
Time (sec)
B
10-sec Mean ± S.E.M
Temperature Change (deg C)
Time (sec)

Subject TD




10 mm



Temperature (°C)
34.8
34.7
34.6
34.5
34.4
34.3
34.2
34.1
34.0
33.9
33.8
9.240
7.392
5.544
3.696
1.848
0.000
9.009
6.006
3.003
0.000
34.7-34.8
34.6-34.7
34.5-34.6
34.4-34.5
34.3-34.4
34.2-34.3
34.1-34.2
34.0-34.1
33.9-34.0
33.8-33.9